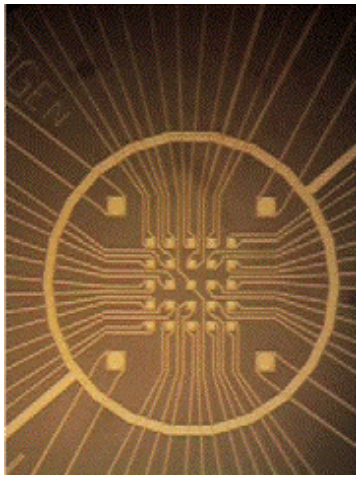
Automated Programmable Electronic Matrix (APEX)

- Two properties of DNA: specificity of hybridization and electrophoretic mobility, form the basis of this technique.
- A microelectrode array to which synthetic DNA fragments are attached enables the manipulation, identification and selection of specific DNA fragments from a population.
- An unknown population of DNA fragments is electronically "addressed" to specific electrodes, facilitating hybridization and immobilization of those fragments that are complementary in sequence to those attached to the electrodes.



Researcher: P. Swanson P.I.: S. Graham Affiliation: Nanogen, Inc.
NNUN Site: SNF

National Science Foundation

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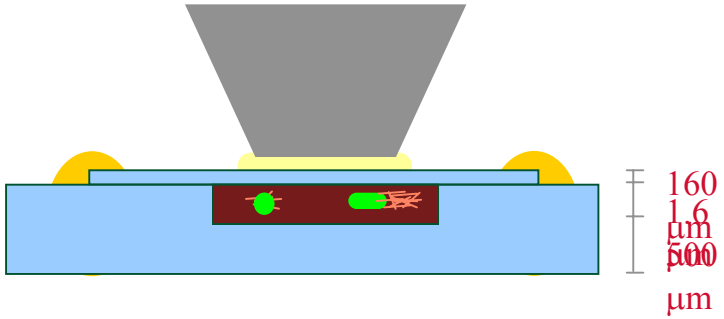
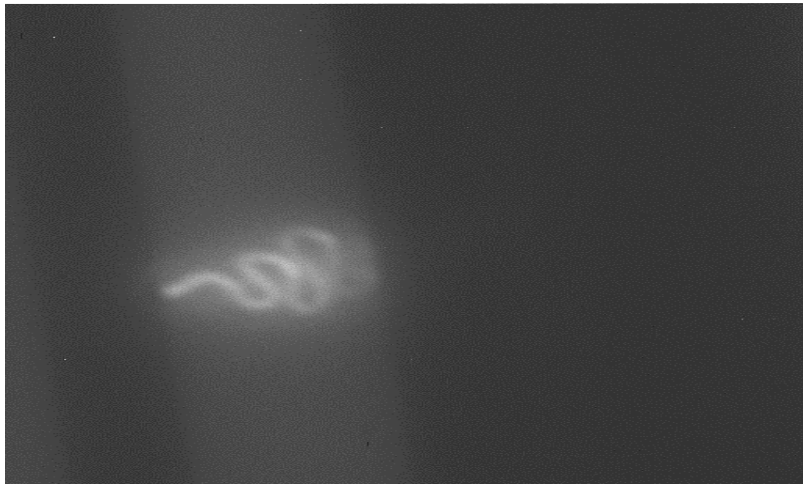
Microchannels for Studying Bacterial Motility

- The idea: create a small chamber with controlled geometry for imaging bacteria. Requirements: 160μm thick cover glass for oil immersion optics, 2μm deep channel. By varying chamber geometry we can ask about effects of chamber wall proximity on speed and variability in bacterial motility, and also calibrate the optical path for analytical readout of protein concentrations in chamber.
- Fluorescence micrograph of an fluorescently labeled actin tail extruding from a polystyrene bead in a Si/Glass chamber filled with cellular extract. A protein, called 'ActA' on the bead triggers the polymerization of the actin in the extract.
- These are the first observations of extrusion of an actin tail off a fixed substrate (in this case a polystyrene bead coated with a triggering protein). The channel architecture allows loading multiple samples in a single preparation, zero background calibration, and geometry control.





Frederick S. Soo, Matthew Footer and Julie A. Theriot
Dept. of Biochemistry, Stanford
NNUN Site: SNF

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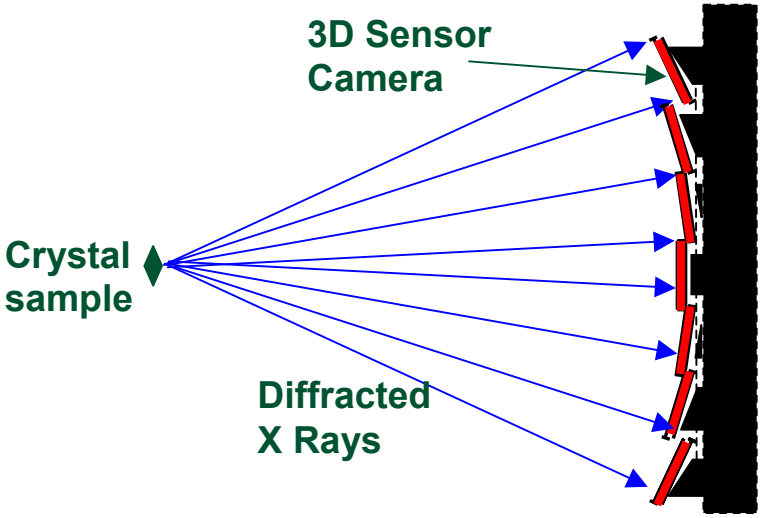
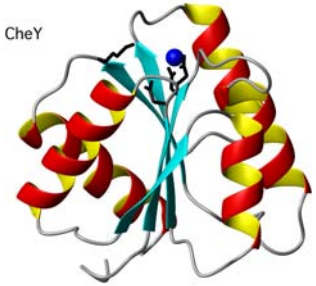
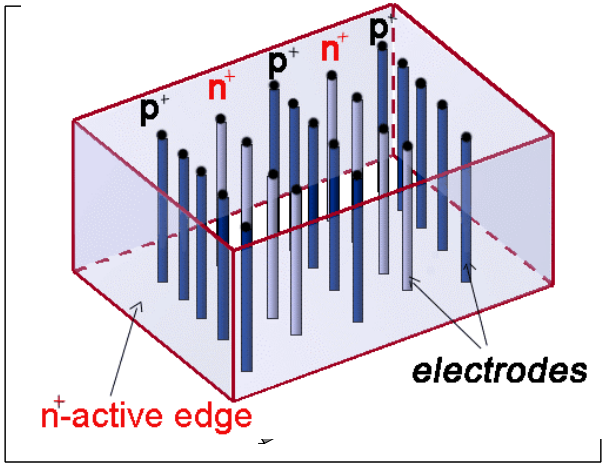
Active-Edge, 3D Radiation Sensors for Protein Crystallography

- New Type of Radiation Sensor
- No Dead Area on Perimeter
- Protein Crystallography Camera
- Electron Beam Tools
- High Energy Physics
- Synchrotron Instrumentation





Courtesy of MBC
Phil Matsumura



Researchers: C. Kenney, Molecular Biology Consortium,
S. Parker, U. of Hawaii, J. Hasi, U. of Brunel
NNUN Site: SNF

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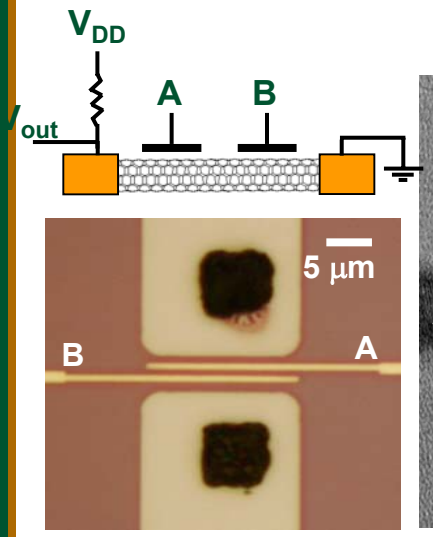
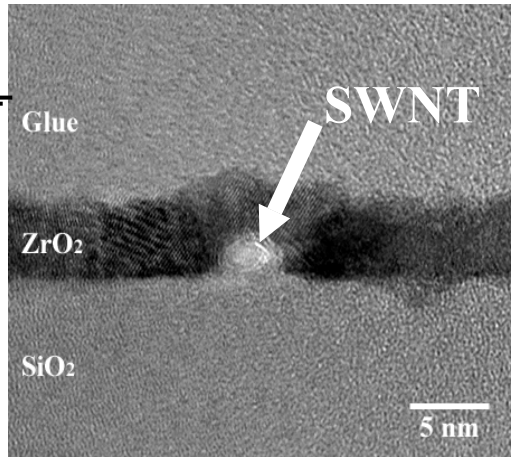
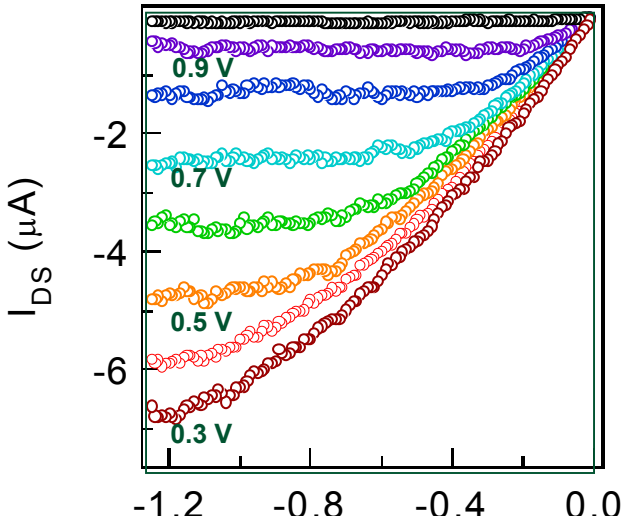
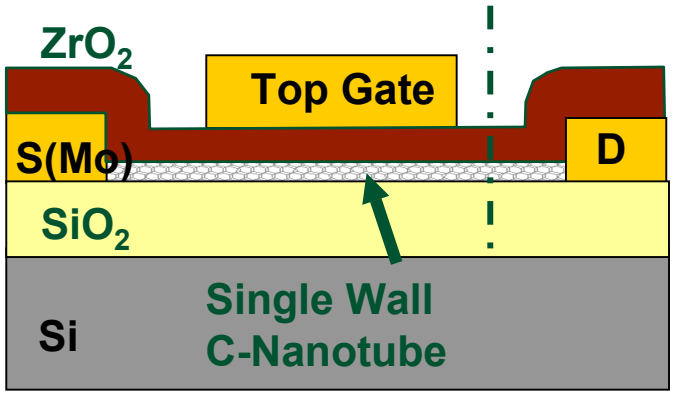
Nanotube Transistors and Logic Gate with ALD-ZrO2

- Excellent performance
- Scalable to sub-10nm channel lengths
- Need controlled growth of nanotubes and ALD-ZrO_2 dielectric.









Reference: Nature Materials, 2003
Dai (Stanford), McEuen (Cornell), McIntyre (Stanford)
NNUN Site: SNF

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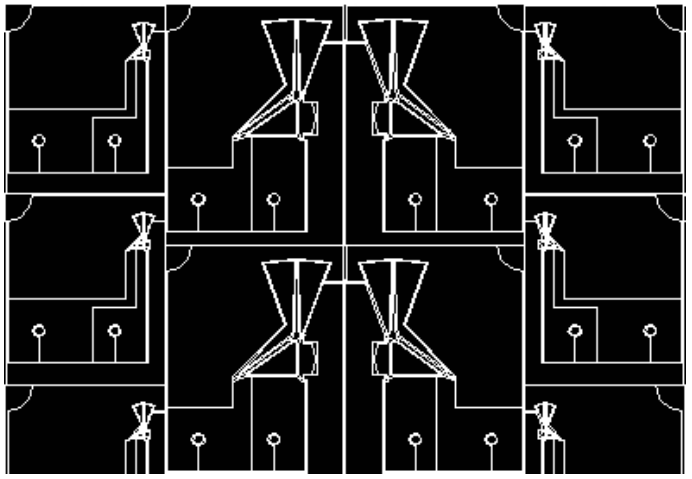
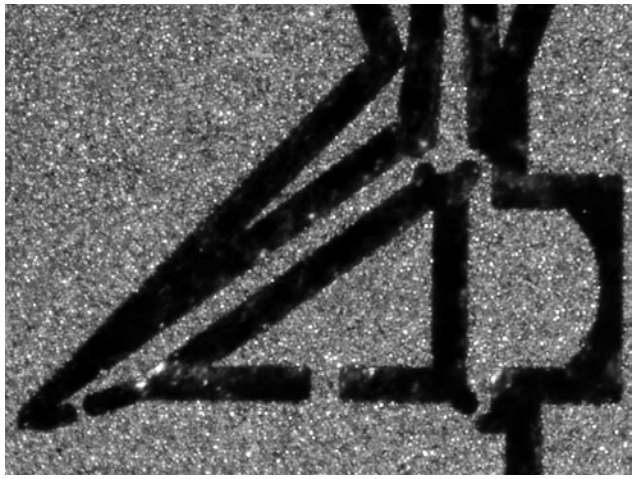
Motion-Amplified Mechanisms

- **Motivation**
  - Adapt traditionally “macro” mechanism design principles to motion-amplification in micro-scale, under process constraints of microfabrication.
- **Accomplishments**
  - Optimized monolithic flexure design to mimic a “four-bar mechanism” using finite element analysis.
  - Fabricated multiple wing spar hinge mechanisms in high-aspect micro-machined silicon.
  - Demonstrated amplification wherein a 12 μm actuation displacement results in greater than 100 μm tip displacement.
- **Experimental work funded by SNF seed grant and researched conducted primarily by undergraduates.**

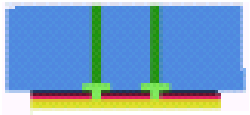


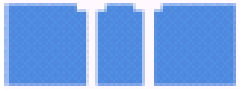


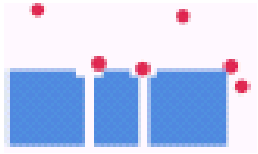
Users: R. Martin, H. Ratia, W. Shi
PIs: S. J. Lee, T. R. Hsu
Mechanical & Aerospace Engr./Chemical & Materials Engr.
Institution: San José State University
NNUN Site: SNF

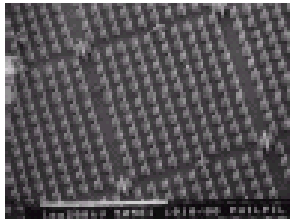
Stanford Ophthalmic Tissue Engineering Laboratory

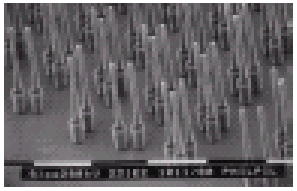
- **Tissue-engineered neurite conduits to connect retinal ganglion cells to an electronic retinal prosthesis.**
- **Combination of microfabraction and self-assembly techniques.**
- Left column, from top: Silicon/SU-8 pillar mold; liquid matrix cast on mold; polymerized membrane removed from mold; cultured cells/neurons seeded on mold; prosthetic device (dark blue) is interfaced with the mold and neuronal growth is directed down to form connections with existing neurons.
- Right column, from top: SEM of mold; higher magnification SEM of mold; matrigel membrane case on the mold; self-assembled array of rat ganglion cells in the cups of the matrigel lamina.

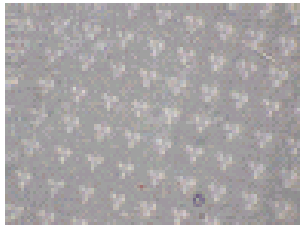


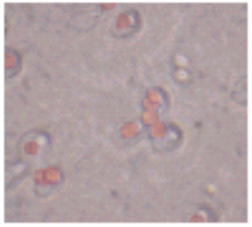


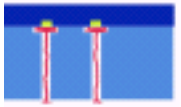












Researcher: Phil Huie, Mark Peterman; PI: Harvey Fishman
Department of Ophthalmology, Stanford University
NNUN Site: SNF

National Science Foundation

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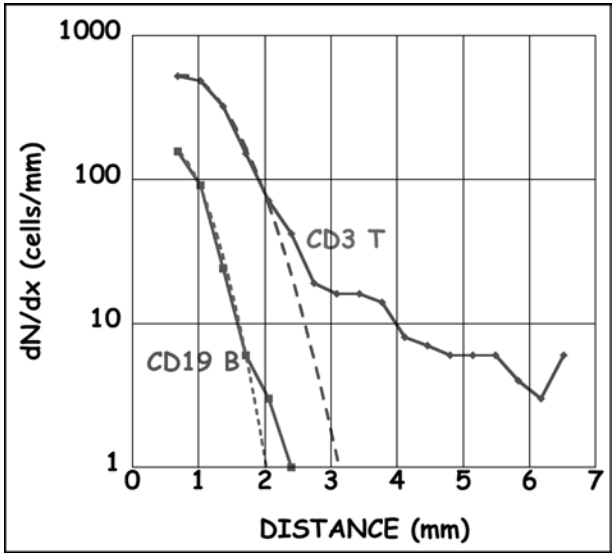
Cell Sorting of B and T Cells

- Cells are heterogeneous with no two cells alike in morphology or epigenetic state. Capturing cells of interest, fractionation and analysis of lysed cells is of major interest for genomic analysis.
- B-cells have immunoglobulins on surface that transform into antibody secreting plasma cells upon stimulation by antigen.
- The deformability and adhesion characteristics of these cells can be employed for fractionation and labeling.
- T-cells are found not to follow the stick-activation law of B cells, and exhibit low power-law tails with deep penetration of microfabricated arrays, indicating great heterogeneity.



Users: C. Prinz and D. Lawrence
PI: R. Austin
Dept. of Physics and Wadsworth Institute
Institution: Princeton University and Wadsworth Institute
NNUN Site: CNF

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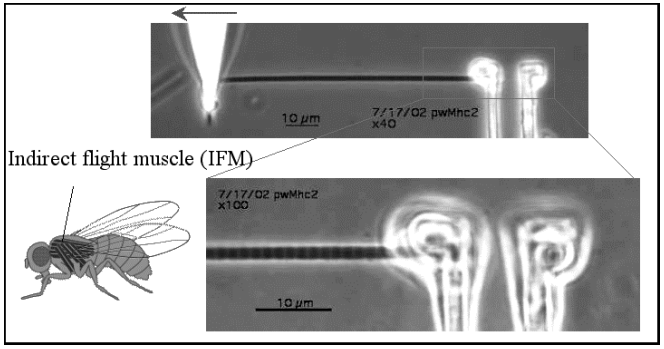
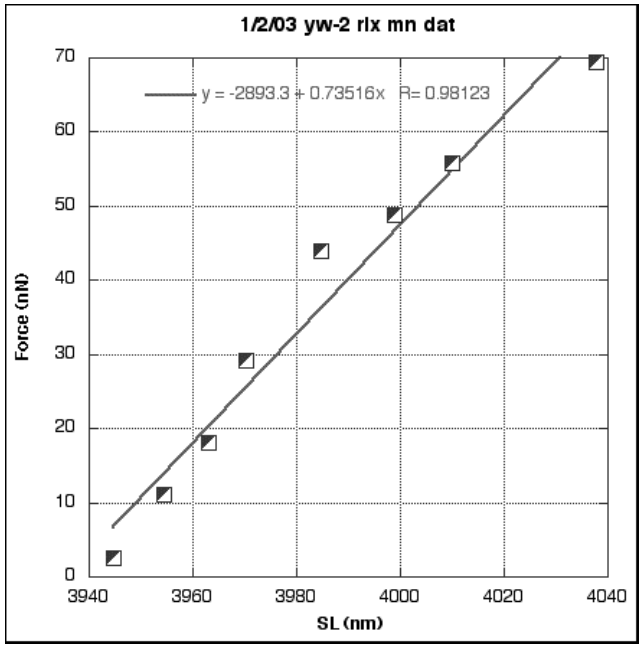
Passive Elasticity of Myofibrils

- Accurate characterization of myofibril elasticity is essential to detection of small changes in muscle mechanics from specific mutation of indirect flight muscle (IFM).
- Drosophilia IFM has been accurately characterized using 12 pN/nm sensitivity silicon nitride cantilevers. Measurement protocol allows length of each sarcomere to be monitored.
- Measurements show good linearity under physiological conditions in highly sensitive measurements.





Users: Y. Hao
PI: G. H. Pollack
Dept. of BioEngineering
Institution: University of Washington
NNUN Site: CNF

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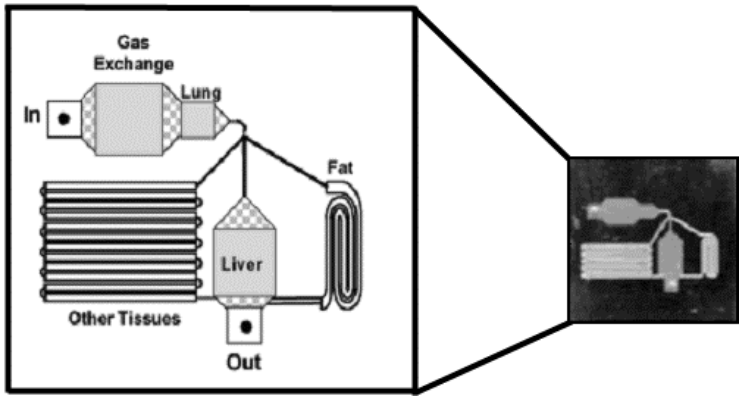
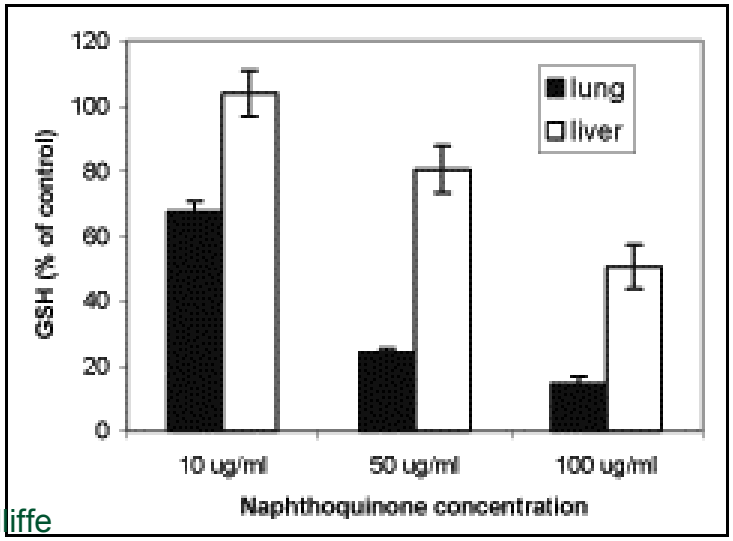
Animal on a Chip: Chemical Exposure Analysis on a Chip

- An in vitro system that can predict human response to chemical exposure is of immense health and environment significance.
- A silicon or polystyrene based device consisting of arrays of channels/compartments that mimic organ systems, with design parameters that mimic residence times and flow distributions allows such an evaluation.
- Proof-of-concept experiments using napthalene as a toxin interacting with “liver,” “lung,” “other tissue,” and “fat” through representative cells show that naphthoquinone and napthalenediol are reactive species responsible for biological response





Gluthathione reduction compared to control

Users: S. Harris, K. Viravaidya, X. Li, D. Tatosian, G. McAulliffe
PI: M. L. Shuler
Chemical and BioMolecular Engineering
Institution: Cornell University
NNUN Site: CNF

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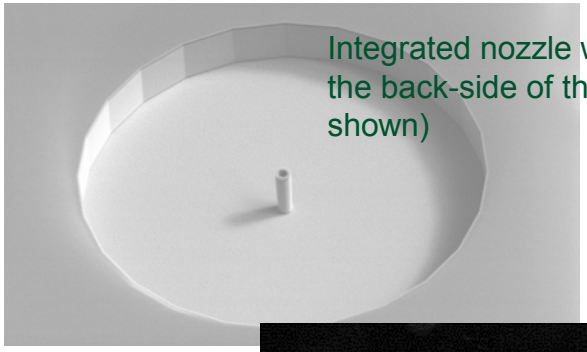
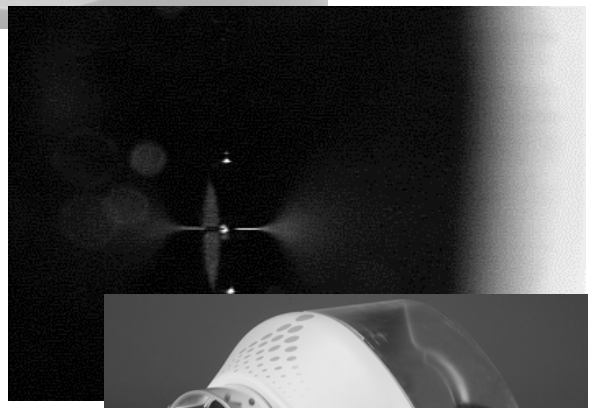
Monolithic ElectroSpray Ionization Chip

- **Monolithic microfluidic devices in a mass spectrometer can enable rapid and pricesse automated infusion analyses of compounds of interest. This is particularly useful in large-scale pharmaceutical industry testing programs, proteomics, single nucleotide polymorphisms, etc.**
- **Single-crystal silicon is employed for creating nozzles and a channel to a reservoir, with 1536 well sample plates, and is interfaced to a mass spectrometer for mass, structure and other quantitative data**
- **These are the most compact and versatile mass spectrometers in existence.**



Integrated nozzle with a chamber on the back-side of the wafer (not shown)

Nozzle in operation



Integrated Workstation

Users: C. G. Alpha, N A> Shinde, J. Li, and J. C. Ackerman
PI: T. N. Corso
Institution: Advion BioSciences, Inc.
NNUN Site: CNF

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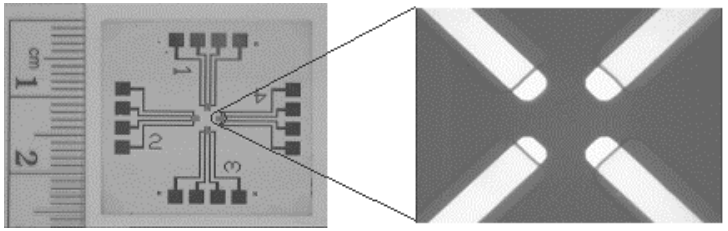
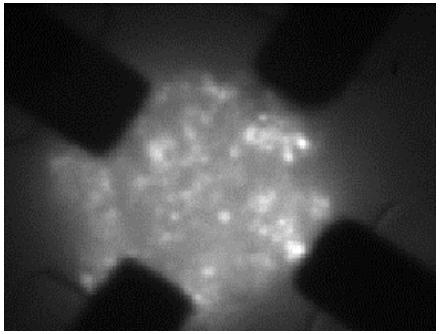
Spatio-Temporal Dynamics of Exocytosis

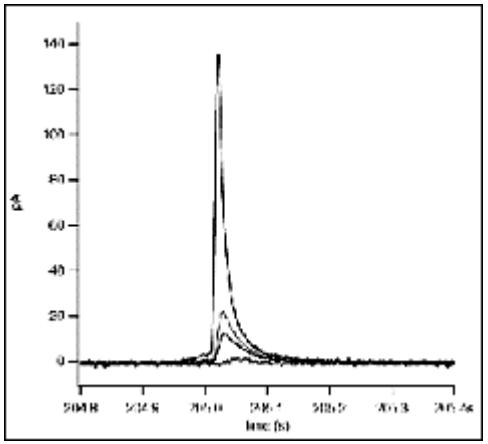
- **Exocytosis is the process by which cells (neurons, chromaffin cells of adrenal gland) release signaling molecules (adrenaline, e.g.). The process is not well understood.**
- **An electrochemical detector array, coupled to a cell, detects the current due to oxidation of the signaling molecule released during exocytosis. Relative magnitude of current at the electrodes due to single event are used to determine location and simultaneous fluorescence imaging through total internal reflection (TIRF) confirms the location of release of event.**





Cell under TIRF illumination with vesicles loaded with acridine orange dye

Current in single exocytotic event.



Users: K. K. Elliott and A. Dias
PI: M. Lindau
Applied and Engineering Physics
Institution: Cornell University
NNUN Site: CNF

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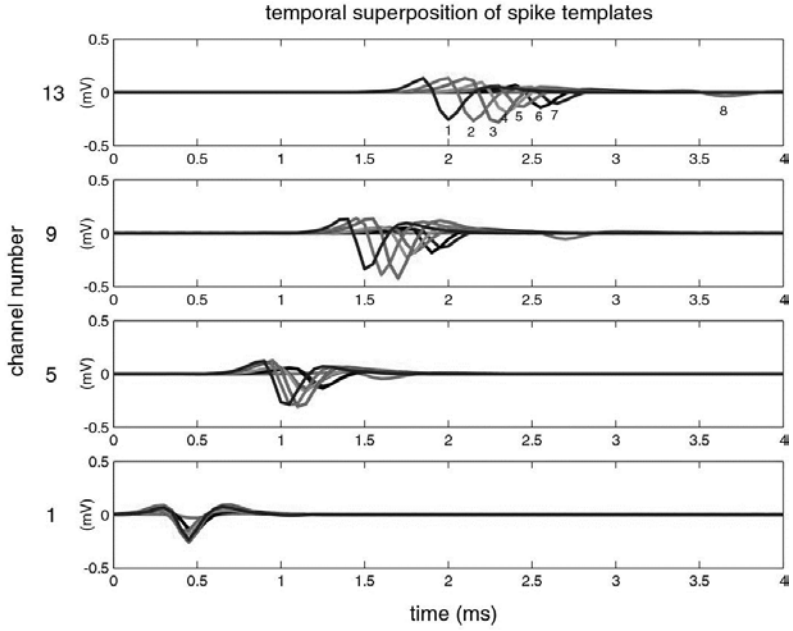
Multi-channel In Vivo Cellular Recording

- One of the most difficult problem in neurobiology is simultaneous recording the activity of several neurons. This is essential to understanding neural network computation.
- This effort has fabricated multi-channel structures that resolve activity of eight units in the cricket ventral nerve cord in siloated activity, and four units in bursts of activity with a large degree of spike overlap. These measurements now allow development of models for neural response.



Users: A. J. Spence
PI: M. Isaacson
Electrical Engineering
Institution: UC Santa Cruz
NNUN Site: CNF

National Science Foundation

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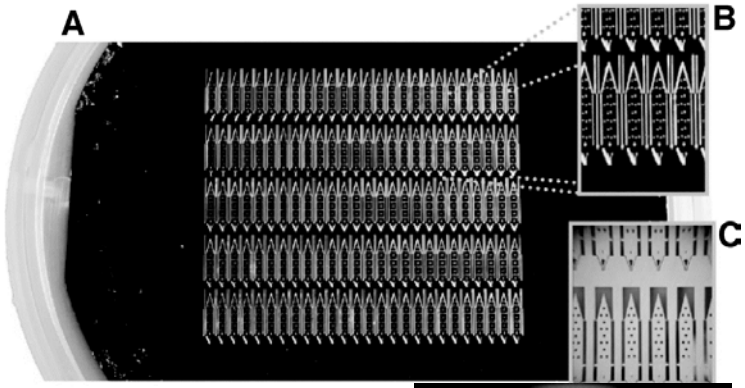
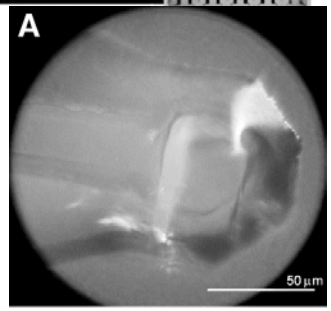
BioMacroMolecular CryoCrystallography Holders

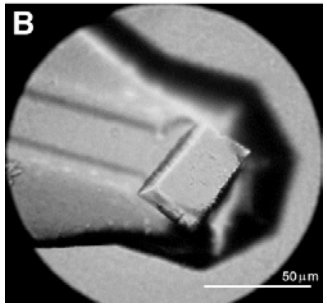
- X-ray crystallography of 3-D structure of macromolecules requires collection of data of flash-cooled crystals at T<120 K. Current methods are irreproducible and work for large crystals.
- This effort has developed a new mount, using flexible material containing small holes connected to a larger opening via a drainage channel that allows removal of excess liquid.
- The mounts are now employed at MacChHESS and ESRF/Grenoble



Arrays of holders



Mounted protein crystal with excess liquid and liquid removed



Users: Z. Stun, J. Kmetko, and K. O;Neill
PI: R. E. Thorne
Department of Physics
Institution: Cornell University
NNUN Site: CNF

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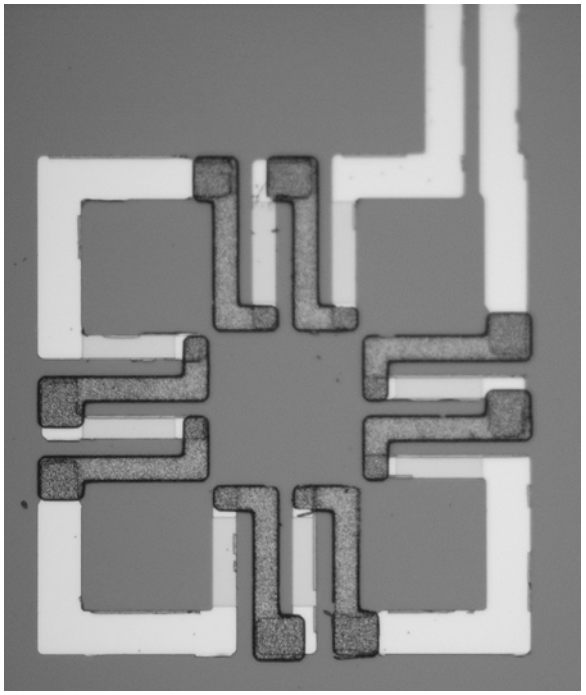
Monolithic PicoCalorimeters

- Disposable pico-calorimeters are likely to b very helpful in basic research in cellular metabolism, enzyme function, functional genomics, etc.
- The picocalorimeter developed is faster than conventional devices (~15 ms instead of 5 s), sensitive by x10^3, and cheap enough to dispose. These characteristics are achieved by using membranes, thin-film thermopiles that allow differential measurements, and 1 K/20 microWatt



Users: M. Radparvar
PI: M. Radparvar
Institution: HYPRES, Inc.
NNUN Site: CNF

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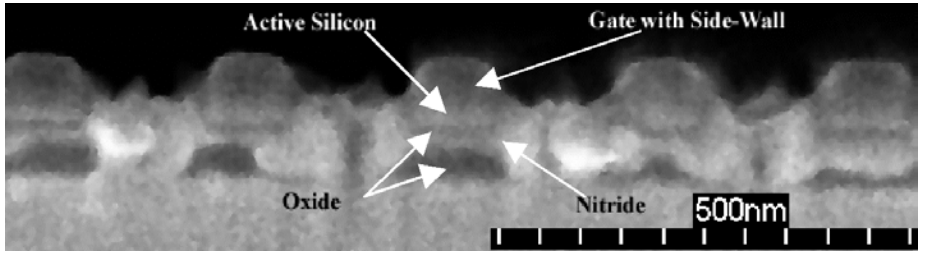
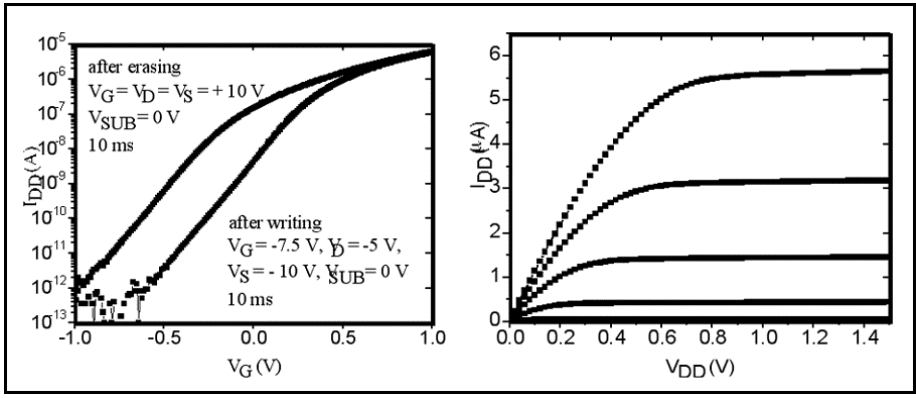
MEMFET: Transistor and Memory at 10's of nm

- Electronics at 10's of nm is searching for highly reproducible, low power, and CMOS-technology compatible logic and memory element
- This effort has demonstrated a new structure that employs a defected layer underneath a silicon channel to create a device that works as a transistor at low voltages and a non-volatile memory at higher voltages. A new wafer bonding technique creates the wafer for fabrication. Devices have on-to-off current ratios of >10^7, and sub-threshold swing of 120 mV/decade, with useful memories employing 10 to 20 electrons.



Memory Array



Users: H. Silva
PI: S. Tiwari
Electrical & Computer Engineering
Institution: Cornell University
NNUN Site: CNF

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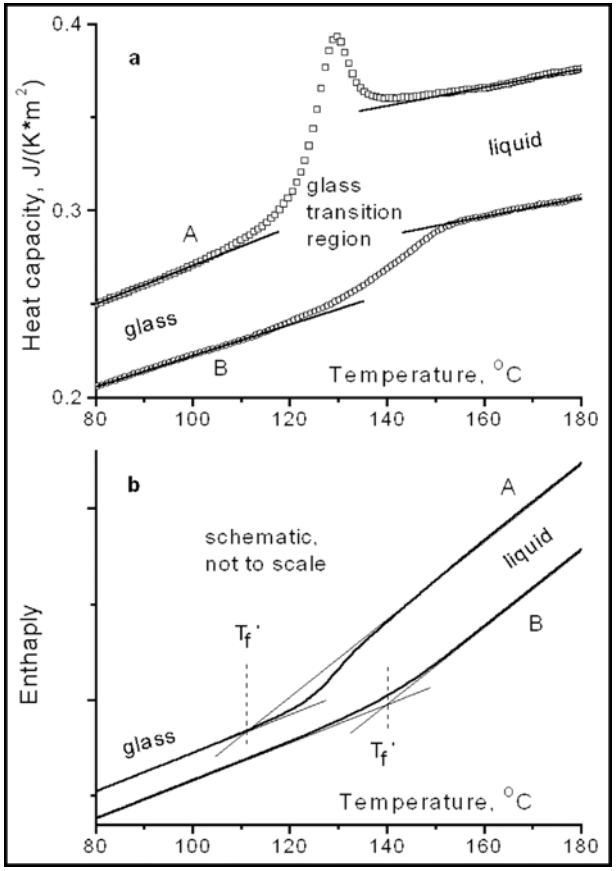
NanoCalorimetry of Polymers and Metals

L. H. Allen, Univ. of Illinois

- **Nanocalorimetry has been applied to precise heat capacity measurements of polymers and metals for very thin films.**
- **Ultra-thin polymer films exhibit large shifts in glass-transition temperature (T_g) whose underlying nature is not yet well-understood. The precise measurements on spin-cast polystyrene [Macromolecules, 35, 1481 (2002)] of this effort are providing information that can be used to understand the energetics of polymer growth at 10's of nm.**
- **The technique has also been applied to obtaining "Cp vs. T vs. t" in-situ data during growth. Evolution of indium particles and size-dependent melting at a resolution of .4 nm in thickness and 30 pJ/K in heat capacity have been demonstrated.**



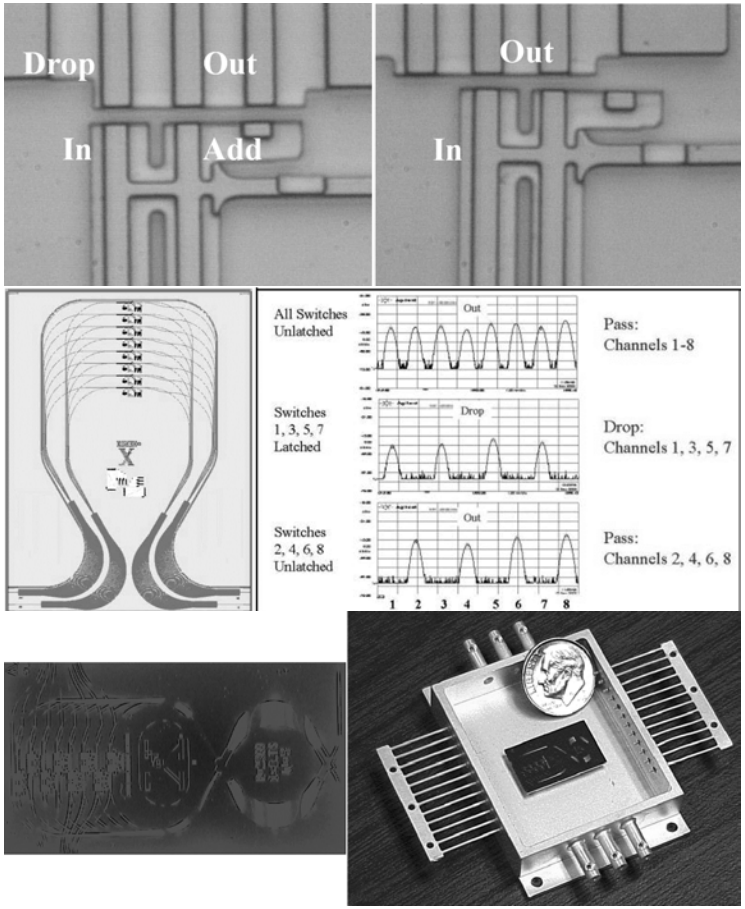
Glass transition in poly-2-vinyl pyridine and poly-methyl methacrylate. Glass transition is shifted higher by 10-20 K and activation enthalpy is shifted lower.

Users: M. Efremov, E. Olson, M. Zhang, and Z. Zhang
PI: L. H. Allen
Materials Science
Institution: University of Illinois
NNUN Site: CNF

NNUN National Nanofabrication Users Network

Chip-Scale ReConfigurable Add/Drop Multiplexers

- On chip integration of optical switching and planar light circuits are critical to optical information routing. Reconfigurability of such structures allows for inexpensive implementation of the routing functions.
- Silicon, SOI, and MEMS-based techniques integrating optics, mechanical, and electrical functions has allowed prototype switches with insertion loss below 2 dB, extinction ratios greater than 40 dB, cross-talk less than 35 dB.



Users: P. Lin and J. Chen
PI: J. Kubby
Institution: Xerox Wilson Center for Research & Technology
NNUN Site: CNF

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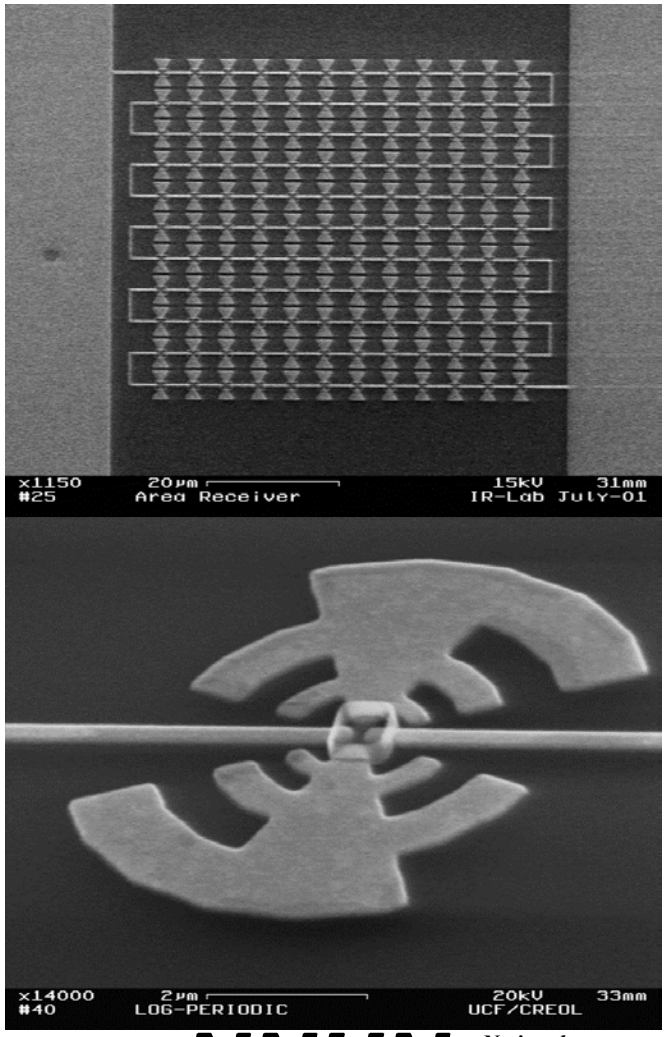
Antenna-Coupled Infrared Detectors

- Antennas allows the use of sensors of dimensions smaller than a wavelength and negligible cross-section for radiation. For infrared, this makes possible bolometers useful for uncooled IR imaging systems. Low thermal mass of such systems can improve the response time by nearly 5 orders of magnitude to 300 ns.
- Antenna-coupled, highly efficient, bolometers have been demonstrated with near-theoretical performance.



Users: J. Gonzales
PI: G. Boremann
School of Optics
Institution: University of Central Florida
NNUN Site: CNF

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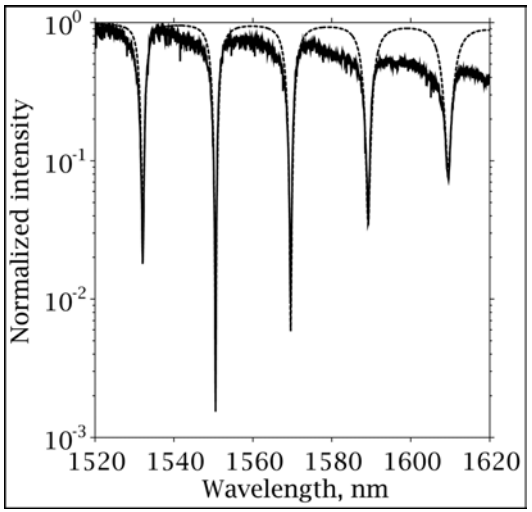
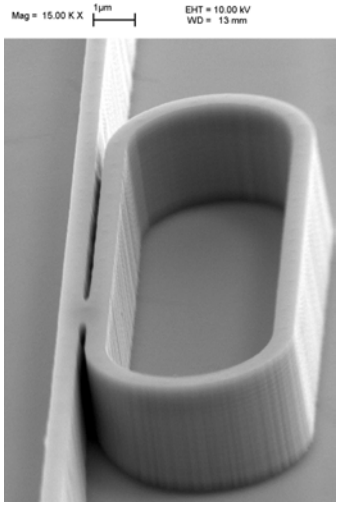
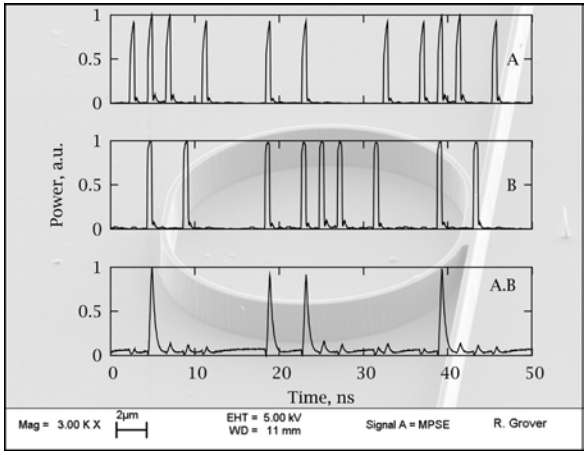
InP-Based Micro-Resonator

- Notch filters are optical structures that are important to optics. Optical structures, however, are usually large in dimensions and there is a lot of interest in compact structures of high performance.
- Micro-ring resonators demonstrated in this effort are the smallest optical micro-ring resonator notch filters and operate in the wavelength range of most interest.
- Resonance tuning of over 0.8 nm is achieved with ~8V bias







Users: Y. Leng, T. Ibrahim and K. Amarnath
PI: R. Grover
Laboratory for Physical Science
Institution: University of Maryland
NNUN Site: CNF

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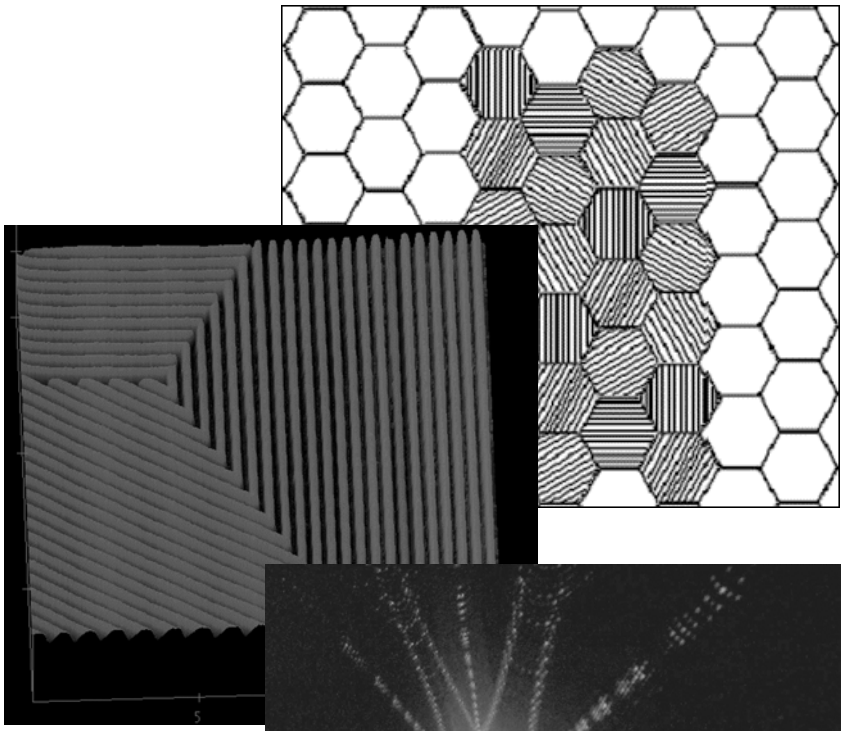
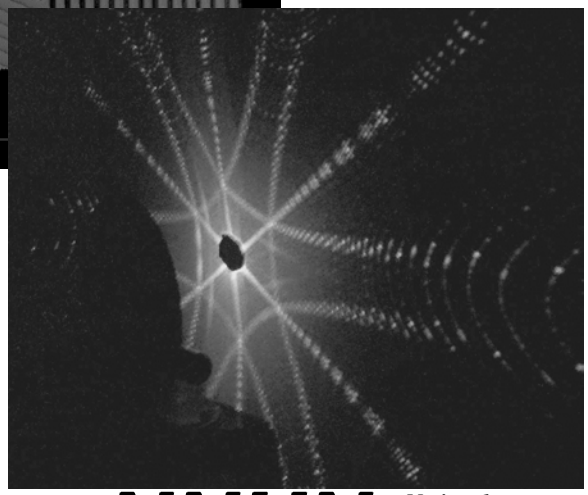
Color Generation in Butterfly Wings

- The Morpho butterfly demonstrates iridescent blue color over wide-viewing angles.
- Microscopy of the wings show up to 24 layers with periodic structure and that the color generation is due to interference formation oby multilayer structure and diffraction.
- Multi-grating structures that mimic the butterfly behavior, where the small size gratings, arranged mostly randomly, diffract white light with the diffracted beams interfering to create wide viewing angles for short wavelengths have been demonstrated.





Diffraction pattern at normal incidence with 488 nm

Users: T-H Wong, B. Robins, and T. L. Levendusky
PI: M. C. Gupta
College of Engineering
Institution: Old Dominion University
NNUN Site: CNF

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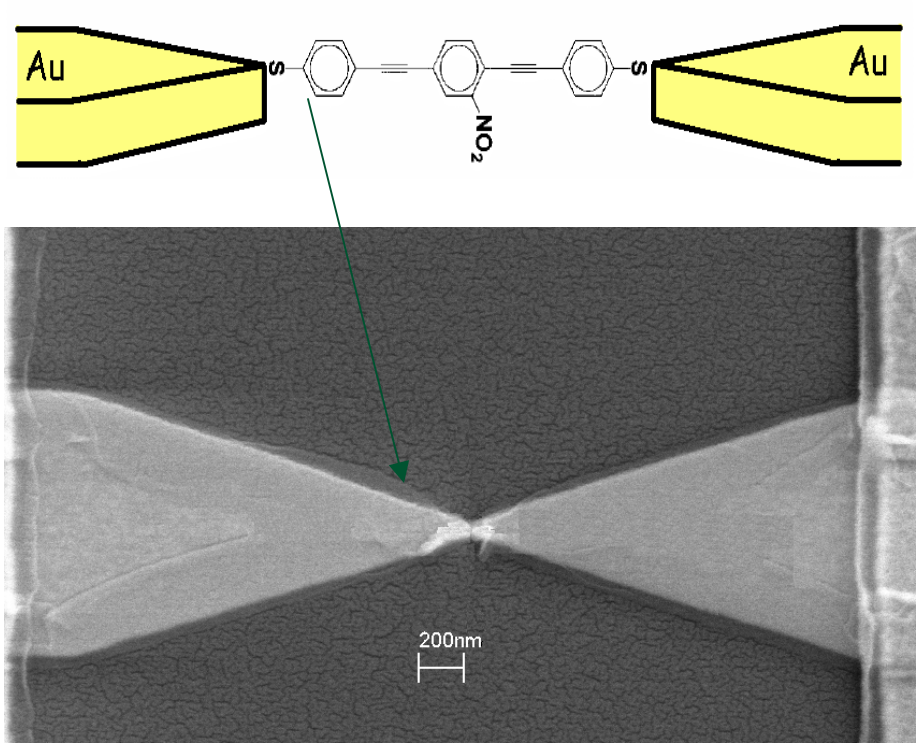
Fabrication of Molecular Electronic Devices

Using electron beam lithography combined with electrical field directed assembly of gold nanorods and electromigration-induced gap formation, structures have been fabricated with nanometer dimension gaps. Using thiol-Au chemistry the gaps have been bridged by ~2 nm long conducting molecules. Preliminary I-V measurements at 10 K show resonant tunneling through discrete vibrational states of the molecules, establishing their presence in the junction. At higher voltages resonant tunneling behavior is observed presumably involving electronic states of the bound molecules. These fabrication methods thus show promise for evaluation of molecules for use in molecular electronic devices.



Example of nanogap test structure

Users: D. L. Allara, Y. Selzer and M. Cabassi
PI: T. Mayer
College of Engineering
Institution: Penn State University
NNUN Site: Penn-State Nanofab

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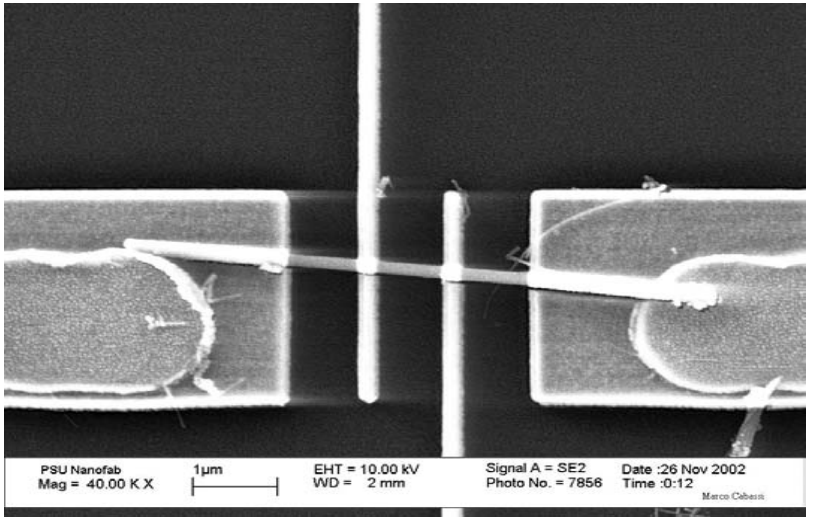
Four-point Resistivity of Intentionally Doped Silicon Nanowires

A method to perform 4-point electrical characterization of Si nanowires has been demonstrated. The nano-wires were grown by Vapor-Liquid-Solid (VLS) growth and have a typical diameter of 200nm. The silicon nano-wires were suspended in solution and electro-fluidically aligned between two large contact pads. Smaller contacts to the nanowire were then defined at two distinct points along the wire's length using electron beam lithography. 2-point and 4-point current-voltage characteristics of the nanowires could then be measured. Preliminary 4-point results were obtained for B doped silicon nanowires.



FESEM image of the measurement structure showing the electron beam defined contacts and anchors. The Nanorods were electro-fluidically aligned.

Users: M. Cabassi, Y. Wang, K. K. Lew
PI: T. S. Mayer and J. Redwing
College of Engineering
Institution: Penn State University
NNUN Site: Penn-State Nanofab

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Controlled propulsion of nano and micro scale devices using catalytic reactions

Nano-objects with spatially defined catalytic zones have been shown to exhibit directed non-Brownian, movement when placed in an aqueous “fuel” solution. These catalytic zones produce interfacial tension gradient-based forces which can serve as nano engines propelling nano and micro scale devices without the use of external electric, magnetic, gravitational, or optical fields.

This work demonstrates the use of these forces to produce controlled motion of practical device structures such as gears and propellers. Figure 1 depicts a Au gear with defined Pt catalytic zones on its teeth. Figure 2 contains 4 photographs of such a gear shown at different angles of rotation immersed in dilute H_2O_2 rotating at ~ 300μm/sec.

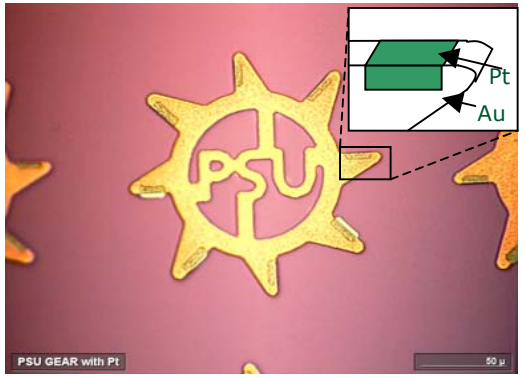

Fig. 1: Gear with Pt coated teeth

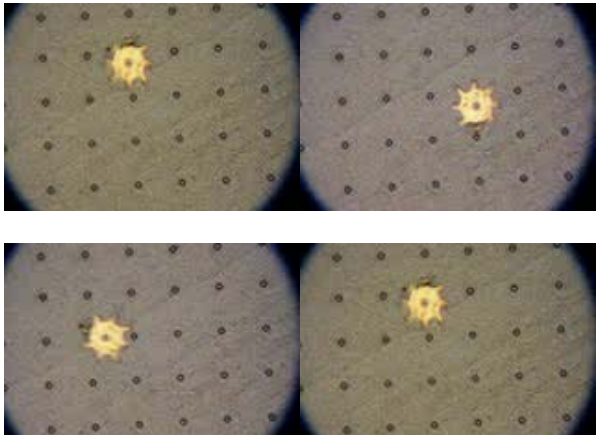

Fig 2: Rotating gear (without PSU) at 0 degrees (a), 90 degrees (b), 180 degrees (c) and 270 degrees (d).

Users: S. Subramanian
PI: J. Catchmark
Institution: Penn State University
NNUN Site: Penn-State Nanofab

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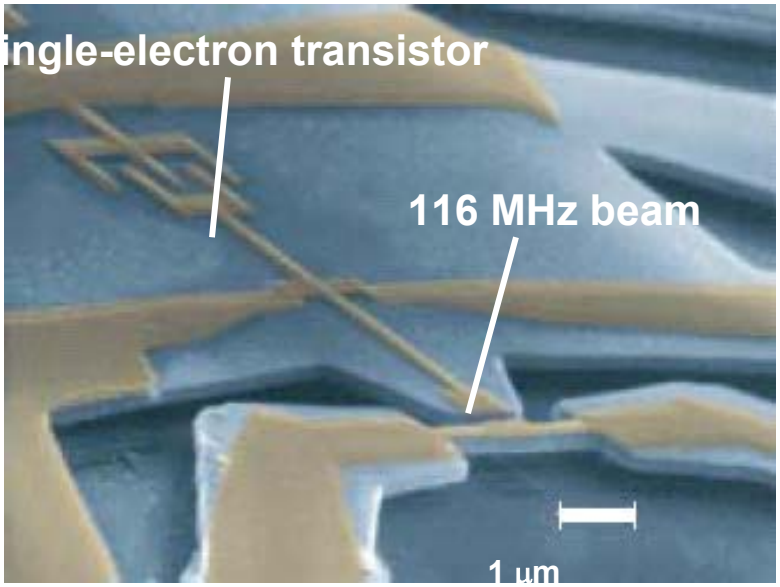
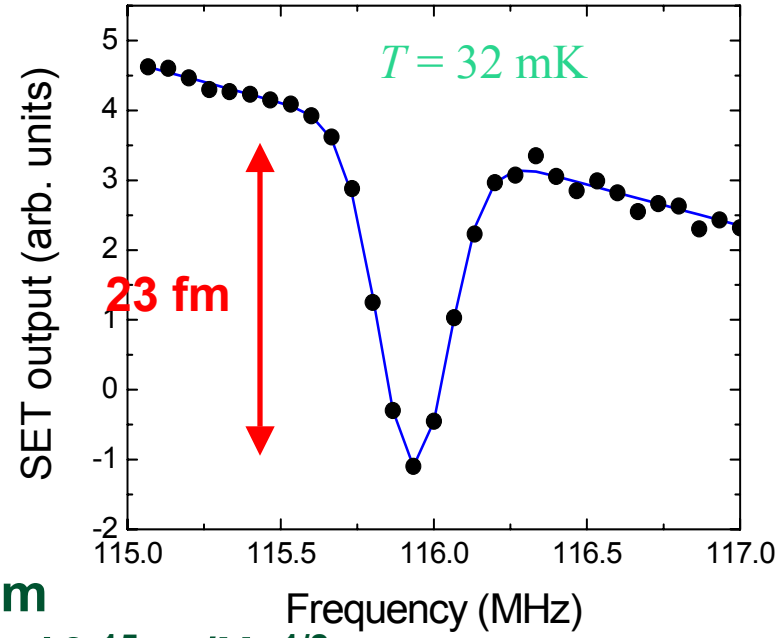
Nanoelectromechanical Systems: Approaching the Quantum Limit in Displacement Sensing





Displacement sensitivity: **10 V/μm**

Displacement noise: $S_x^{1/2} = 1.8 \times 10^{-15}$ **m/Hz$^{1/2}$**

Device approaches zero-point motion sensitivity have been achieved by coupling motion to single-electron transistor sensitivity

Users: R. Knobel
PI: A. Cleland
Institution: University of California at Santa Barbara
NNUN Site: UCSB Nanotech

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